

# SOLAR ARRAY MODEL CORRECTIONS FROM MARS PATHFINDER LANDER DATA

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## ABSTRACT

The MESUR solar array power model initially uses assumed values for many input variables. After landing the early surface variables such as array tilt and azimuth or early environmental variables such as array temperature can be corrected. Later environmental variables such as tau versus time, spectral shift, dust **deposition**, and UV darkening are dependent upon time, on-board science instruments, and ability to separate effects of variables. Engineering estimates had to be made for additional shadow losses and Voc sensor temperature corrections. Some variations had not been expected such as tau versus time of day, and spectral **shift** versus time of day. Additions needed to the model are thermal mass of lander petal and correction between Voc sensor and temperature sensor. Conclusions are: the model works well; good battery predictions are **difficult**; inclusion of Isc and Voc sensors was valuable; and the IMP and MAE science experiments **greatly** assisted the data analysis and model correction.

## BACKGROUND

The Mars Pathfinder (MPF) solar array power model, MESUR, uses a surface insolation model of Viking Lander data derived at NASA-Lewis by Applebaum and Landis [1] as a starting point. The first iteration of MESUR, entitled MARSARAY [2], was quickly developed in BASIC to allow early power estimates and array IV curve generation for project planning. After refinement, MARSARAY was coded in FORTRAN77 and used for detailed operations planning. The FORTRAN model, MESUR, was then extended to include subroutines for: battery charging; battery state-of-charge; shunt regulation; battery temperature calculation; bus **voltage** determination based on battery condition, shunt setting and loads; and detailed array shadowing. MESUR is now being used by the MPF lander power subsystem operator and separately as a module of the MPF operations planning software, **PLAN\_IT\_II**.

### Before Landing

Out of necessity MESUR originally used assumed Mars atmospheric and environmental data as well as **shadowing** and horizon masking models. Just before MPF landed, Earth and space telescopes took pictures which showed the Mars atmosphere as being unusually clear at the landing site. This data was used to modify the atmospheric optical opacity, tau, value in MESUR which changed power predictions. The

lander thermal predictions were also changed since atmospheric dust is known to affect both day and night temperatures.

### Landed Operations

In order to assess MPF power capabilities, the power subsystem operator received 136 channels of different data elements. The data elements are grouped as follows: battery, solar arrays, bus, relays, measurement status, and battery charge parameters. Of special interest are: solar array current; bus voltage; array and battery temperatures; shunt current; battery charge and discharge current, and **state-of-charge**; Voc cells open circuit voltage; and Isc cell short circuit current.

The **silver-zinc** secondary battery on the lander requires the most attention since it degrades quickly and is limited to 30-100 recharge cycles. This means that successful mission operations support requires the replacement of assumed values with measured values as soon as possible. Solar array and battery data gathered or derived during the current day is used by **PLAN\_IT\_II** to determine the power profile estimates for the following day. These estimates are then used to determine the **extent**, nature and timing of mission operations for the next day. This requires that the telemetry data be analyzed and incorporated into the model within six hours of receipt. Below is a discussion of this effort.

## DATA DEFINITION

Mars landed data for MESUR can be broken into three types: early surface and environmental data, later atmospheric and environmental data; and engineering estimates. **Early** surface and environmental data consisted of: lander latitude, lander **twist** (orientation of the rover petal to local North), horizon masking, air bag intrusion, array tilt and tilt azimuth, array temperature, atmospheric opacity, and surface **albedo**. Lander latitude was determined from a combination of navigation data and ground triangulation. Note that ground triangulation was not possible for the Viking landers since they did not have the prominent hills that are visible from MPF. Lander **W&W** was determined from angles obtained during sun acquisition by the **Imager** for Mars Pathfinder (IMP) camera. Early nearby and horizon camera scans defined air bag intrusion and horizon masking. Array tilt and tilt azimuth were determined from on-board accelerometer data. **Early** environmental data consisted of temperature, tau, and surface

albedo. Array temperature was monitored on each of the three petals and was also obtained from the open circuit voltage (Voc) instrument. Tau and Mars surface albedo were measured by IMP.

Later data consisted of a table of daily tau values; a table of tau versus wavelength and time for use in a preliminary calculation of power correction from spectral shift; and array power versus time for use in shadowing and air bag intrusion loss estimation. Later environmental effects data consisted of improved estimates of array operating temperature and the gradual power loss from dust accumulation or UV darkening.

Engineering estimates had to be made and entered into the model in cases where the data was not conclusive. Obvious problem areas are a combination of air bag intrusion and shadowing or dust accumulation and UV darkening. Resolution of these problems can be aided by data from other sensors or science experiments.

### DATA ANALYSIS

The detailed analysis sections were all done concurrently with mission operations support and by discussion with mission science investigators who often made much appreciated helpful inputs.

#### Mars Insolation

The MESUR model uses a triple integral polynomial function from Pollock et al [3] to account for insolation changes due to zenith angle, optical opacity (tau), and albedo. This approach gave good results but no allowance had been made for variable tau and variable spectral shifts during the day (see Fig. 1).

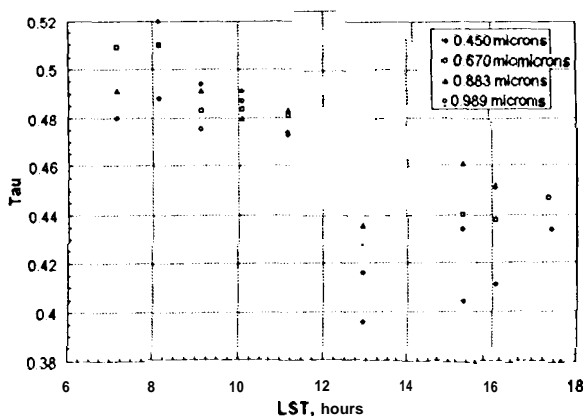


Fig. 1. Tau at four different wavelengths during a typical day,

The presence of ice clouds in the morning was detected by IMP and explained the high early morning readings while the afternoon increase is assumed to be due to thermally created dust or a reappearance of ice clouds. Numerous indications of dust devils were measured but neither this or any other mechanism is confirmed as a contributor to an afternoon

increase in tau. There is some decrease in blue filter light in the afternoon which supports the ice cloud theory.

Spectral shift is also present (see Fig. 1) and is certainly due in part to the ice clouds. No contingency analysis had been made for this effect and as yet there is too little optical data to allow a rerun of the delta-Eddington analysis for spectral corrections at different tau and zenith values. Fortunately the spectral correction coefficients were small in MESUR.

#### Power Estimates

After applying the measured tau value the model power estimates were initially about 12°A too high at noon and 20-30% too high in morning and afternoon without any known cause. The rover was deployed from its petal late in the second Mars day (Sol-2) which removed an obstruction and a source of significant shadowing. The discrepancy was fully explained on Sol-3 when the IMP was extended to its full height and pictures taken from this improved viewpoint showed significant air bag intrusion onto the solar arrays and a wayward piece of the bridle deployment control tape on the rover petal. The air bags cause morning and afternoon shadow losses while the bridle tape and some air bag portions cause all day shadows.

Shadowing is the most difficult modelling challenge since tests show different effects from shadowing different cells in a string and different shadow percentages. Despite the difficulty a detailed shadow loss analysis was incorporated into MESUR before landing by Ewell to account for known shadows from the instrument package, camera, high gain antenna, and atmospheric science (ASIMET) mast.

Due to the press of operations a correction table was initially used to modify the model to account for additional shadowing and any other unknown power losses. Later when estimates were made of the shadowing effects from the air bags and bridle, the modeled power curve matched the measured data well except for early morning and late afternoon (see Fig. 2).

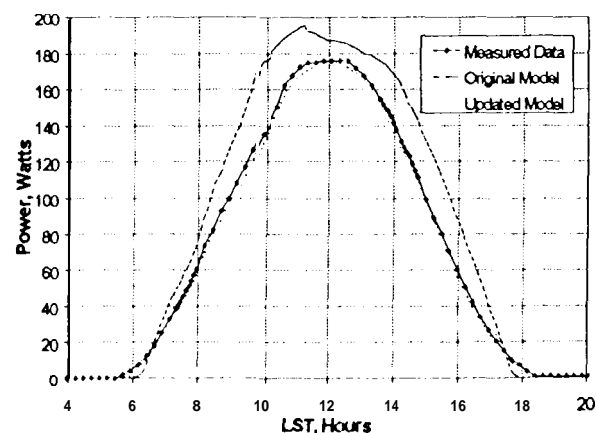


Fig2. Modeled and measured power curves before and after corrections.

- The **early morning** and late afternoon differences are due to two factors. First, MESUR uses an early morning and late afternoon diffuse light algorithm which assumes a  $10^\circ$  half cone angle equally illuminated disk around the sun at a tau of 1. The modeled disk angular size varies as the square root of tau. This is obviously too crude an approximation and needs to be **revised**, especially for missions near the poles. Second, the dust clouds seem to extend to about 45 kilometers and the ice clouds to about 15 kilometers which creates a lot of early morning and late afternoon diffuse light.

### Voc and Isc Sensors

There was one set of Voc and Isc sensors on the lander petal which included the ASI/MET mast. These sensors were placed near the tip of the petal and the base of the science mast to avoid the instrument package shadows and give measurement support to the science instruments. Unfortunately the twist orientation of the lander put the mast **nearly** due south of the sensors so there is a mid-day shadow problem for both sensors. Even with this problem the Isc sensor data has been useful as a cross check on the NASA Lewis Materials Adherence Experiment (MAE) [4] for measurement of dust deposition. The MAE also used an Isc sensor but in addition had a glass cover over the sensor that could be pivoted to one side. This allowed differential readings and thereby avoided sensitivity to changes in tau (see Fig. 3).

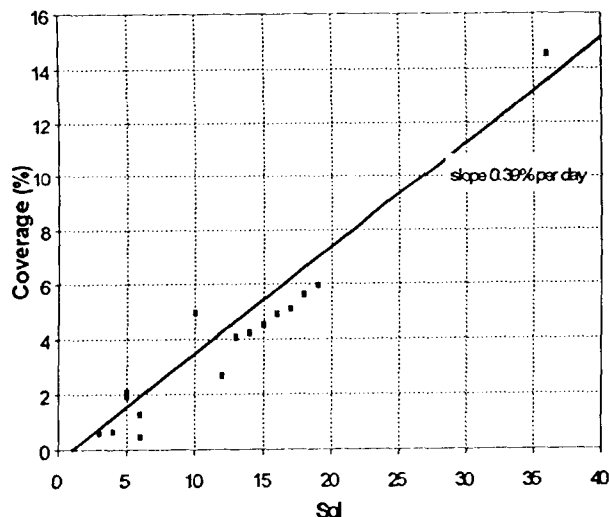


Fig. 3. MAE Isc sensor data

The first ten days of tau values seem to have an average tau value of 0.47 while the remaining days seem to have an average tau value of 0.52. Since there is considerable diurnal variation and day to day variation in tau, it was decided to assume a constant value of tau of 0.5 for the analysis. The linear regression line of MPF Isc differences has a value of  $y = 0.20\%$  per Sol (see Fig. 4). This is compared to the MAE data of  $y = 0.39\%$  per Sol.

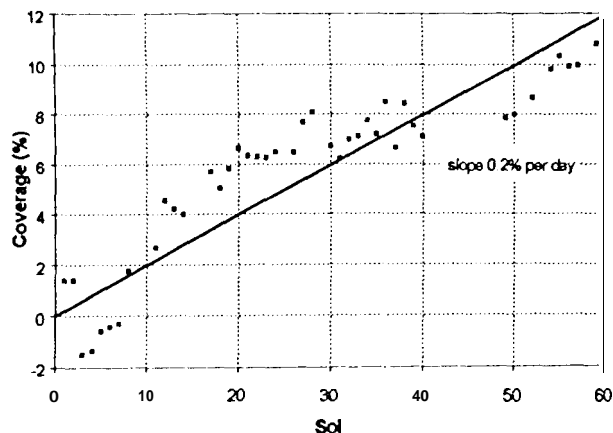


Fig. 4. Differences between Modelled and Measured MPF Isc data.

The MPF Isc data was derived by subtracting measurements made in the time interval from 13.0 to 14.0 Local Solar Time (LST) from modeled values in the same time period. This time was chosen to give the most predictable readings by avoiding the morning ice clouds, the mast shadow and afternoon dust or ice clouds.

The Voc sensor experienced cutoffs earlier each evening due to lack of light. A Voc sensor voltage of about 1.7 Volts corresponds to the time of sunset. While this trend was expected as Mars is approaching its autumnal equinox, sunset occurs only seventeen minutes earlier by Sol 55. However, a 26.4 minute changes was measured at a Voc sensor voltage of 1.7 Volts which corresponds roughly to the time of sunset, and a 61.5 minute change was measured at a Voc sensor voltage of 0.4 Volts (see Fig. 5).

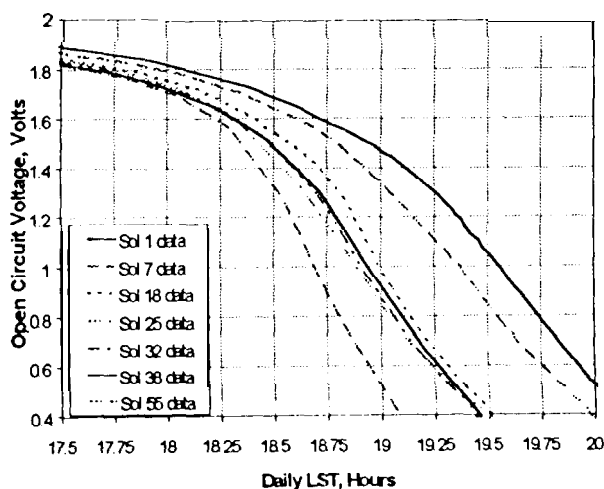


Fig. 5. MPF Voc sensor cutoff times.

This finding is unfortunately sensitive to  $\tau$ . Since the Voc cutoff times are sensitive to insolation the insolation was modelled at Sol-1 and Sol-55 with  $\tau$  values of 0.45 and 0.55 respectively. The same insolation values were found to occur at 18.15 and 17.85 which would give a 18 minute difference in cutoff time. A measured 26 to 62 minutes implies a  $\tau$  value of greater than 1.0 which is higher than any measured. Thus, this is another indication of dust deposition,

### Temperature Sensors

Temperature predictions were initially higher in mid-day than measured and the modeled peak temperature was at noon instead of about 13.5 as measured. The first issue addressed was magnitude (see Fig. 6).

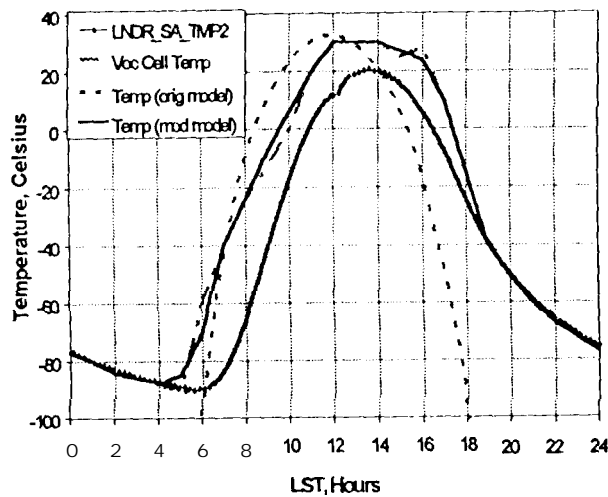


Fig. 6. Comparison of modelled, measured and modified temperature curves

The reason for the higher predicted temperatures was the difference in absorptivities between the temperature sensors and the solar cells. When the Voc sensor data was analyzed for temperature it was used to create the modified curve on Figure 5. Note that this curve is very close to the measured curve except for time of day. The difference in timing of the peak temperature is due to lack of inclusion of thermal masses for the lander petals and air bags.

### Comments

Active mission power subsystem operations can enhance mission operations and thus the gathering of scientific data. Since there are two power sources and limited telemetry bandwidth, the daily power estimate cannot be completely accurate. Load sharing between the solar array and the battery requires use of many data elements which have only limited accuracy due to digital to analog conversion rounding and the limited number of available bits.

The daily power estimate has some limitations. This is because of the uncertainty of the bus voltage which is

dependent on the battery state. The battery state-of-charge calculation was especially difficult since measurement and rounding errors accumulate and the spacecraft suffered some computer resets which zeroed out the on board amp-hour integration. In addition, since silver-zinc batteries degrade rapidly, it is also very difficult to estimate what their capacity is as the mission progresses.

### ACKNOWLEDGEMENTS

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### CONCLUSIONS

The MESUR model made very accurate solar power predictions once assumed values were replaced by measurements.

The battery predictions were less satisfactory since the Ag-Zn battery changed rapidly.

Inclusion of Isc and Voc sensors provided useful analytical data to both scientists and power subsystem operators.

The IMP and MAE scientists and science data were both very valuable in analyzing MESUR performance.

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